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SUITABILITY OF BEETLE-KILLED PINE IN COLORADO'S FRONT RANGE FOR WOOD AND FIBER PRODUCTS

SUITABILITY OF BEETLE-KILLED PINE IN COLORADO'S FRONT RANGE FOR WOOD AND FIBER PRODUCTS

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I. INTRODUCTION

The easternmost mountains of Colorado constitute the Front Range, a mountain belt about forty miles wide which is part of a continuous chain of mountains extending from the North Platte River in central Wyoming to the Arkansas River in south-central Colorado, but for purposes of this study is confined to the Colorado portion of the chain. The high mountains are craggy areas of bare rock extending well above the timber line. Larger parts of the mountain areas are of lesser elevation and present a rough, but less dramatic topography covered by pine and spruce forests. The entire area consists of approximately 820 thousand acres of sawtimber, 808 thousand acres of poletimber and 90 thousand acres of seedlings and saplings. The ponderosa pine type includes about 300 thousand acres of sawtimber (238 MMCF) and 128 thousand acres of poletimber (136 MMCF). The other wood species of importance in the area are Engelmann spruce, subalpine fir, Douglas-fir, lodgepole pine and aspen. The total acreage of dead trees in the area has not been accurately determined; however, the volume of dead trees is estimated to be more than 466 million cubic feet. The growing stock in the affected area is estimated to be 2.18 billion cubic feet of sawtimber, poletimber, and seedling and sapling.[1/]

The mountain pine beetle epidemic in Colorado Front Range ponderosa pine has been identified by the U. S. Forest Service and the Colorado State Forest Service as one of the most urgent forest management problems in the region. A USDA Forest Service Region 2, preliminary report for "Western Forest Insect Problem Area Analysis" estimates an annual mortality of 27.3 million cubic feet in the Front Range caused by the mountain pine beetle. These losses are expected to continue at the current level and possibly increase if action is not taken to curb the outbreak.

[1/] All figures compiled from Tables 4, II-1, IV-1 and VI-1 of Love, R. et al. Unpublished paper. Rky. Mtn, For & Range Exp. Sta. USDA For. Serv. (24).

An effective program to control the beetle epidemic requires vegetative management so that the standing timber can be placed in a healthier growing condition. Silviculturists have concluded that vigorous growing trees are less susceptible to insect attacks. To be economically feasible and to meet national conservation objectives, it will be necessary to increase utilization of wood and fiber from the threatened living trees, recently killed trees, old standing dead trees and some of the non-threatened living trees.

Along with an assessment of wood raw material potentially available in the Front Range region and of industrial capacity required to use the wood, an evaluation is needed to determine the suitability of the wood and fiber for various products. This study is primarily directed to dead material which has been beetle-killed within the last five years, its suitability for various products, and determination of properties that may affect or limit its use.

The annual mortality of ponderosa pine trees amounts to a staggering 5,584 thousand cubic feet. This is approximately equal to the present annual harvest of all species in the Front Range. The magnitude of the utilization requirement is compounded when the beetle-killed volume is superimposed on current mill capacities. Salvage and harvesting activities are limited economically by low volumes per acre and inaccessibility of part of the area. Further complicating utilization is lack of technology in the area's industry that will be required to expand the utilization level. The principal purpose of this study is therefore to define some of the problems attendant to utilizing beetle-killed trees and to evaluate some of the more significant utilization related properties of this material.

This project was pursued to identify the types of products currently being produced and the processing being used by the Front Range wood-using industry. Emphasis was placed on the suitability of the raw material and the quality of the products being produced. A basis of judgment was considering the recovery obtained from the raw material. Some attention but not exhaustive was given to new products not now being produced. Every effort was concentrated on evaluating the suitability of the raw material within the time restraints.

The utilization of the Front Range pine is not entirely dependent on the technical characteristics of the raw material and product requirement but depends also upon the harvesting, transportation and processing cost. Comparison of the costs of between dead timber and the material from live trees should provide a reasonable basis for assessment. Other parts of the overall study are likely to give more definitive information on costs, type and size of markets of products from beetle-killed pine, but the technical characteristics and existing knowledge of product and product values are valuable in projecting the extent of the markets.

II. Material Evaluation

A. Physical Stem Characteristics

The ponderosa pine timber resource covers a wide range of age classes and site conditions. The vigor of trees in the stands varies greatly. The beetle-killed trees are in scattered clusters and have been dead for varying periods of time. To control the beetles some of the living trees also need to be cut from crowded stands to improve health and vigor of the remaining trees. Typically aberrations in tree form result from poor natural pruning of limbs and unfavorable growing sites. Large ponderous branching results, producing patterns of large knots in lumber cut from these stems, which also

tend to have a high degree of taper. Two of the more commonly found types of damage found in standing dead ponderosa pine timber are broken tops and fire or lightning scars at the base of tree. Trees dead over two years also develop prominent checks in the wood. These checks often appear in places where the wood is exposed as the bark loosens or falls off.

Stem form features, such as lean, sweep, crook and fork, are frequently observed. These stem characteristics in the standing trees can be directly related to grade yield and usable volume for one or more primary products (12, 13).

Fungi and insect galleries are ever present in wood of beetle-killed trees. The inner bark is characterized by numerous main vertical bark beetle galleries and secondary ones branching off laterally. In a period following the bark beetle attack there is a secondary attack of the sapwood by ambrosia beetles. There presence in the wood results in a pronounced qualitative and quantitive change in wood properties and product yield. The extent of their presence in the trees is directly related to the length of the time the trees have been dead and greatly affects the appearance of the wood.

Current estimates are that five years is the maximum period of time standing trees can be salvaged; however, considerable deterioration is noted during and after the third year.

B. Wood Properties

The suitability of beetle-killed ponderosa pine wood for products depends upon several wood properties, such as specific gravity or density, shrinkage, shock resistance, mechanical strength and visual characteristics. Some knowledge of the other properties of the wood such as pH value, wettability and extractive characteristics is also necessary for ascertaining suitability for other wood products.

a. Wood appearance.

The appearance of the wood from trees that have been beetle-killed is very distinctive and often aesthetically pleasing. All the wood cut from standing dead trees is heavily blue-stained soon after mortality. Blue-staining is caused by two principal species of fungi, namely, Ceratocystis montia (Rumbold) Hunt and Europhium clavigerum Robinson & Davidson. Blue-staining fungi are synergistic with the mountain pine beetle (Dendroctonus ponderosae) and invariably invade beetle-killed trees.

Figure 1 displays freshly exposed cross-sections of beetle infested ponderosa pine logs. An unusual feature is the marked tendency of the stain to appear in radial streaks or wedge-shaped areas in sapwood. This is caused by the tendency of the blue-staining fungi to confine their activities to the wood parenchyma tissue of the sapwood, and the proponderance of parenchyma is found in the wood rays. Quite often associated with blue stain is a pink or purple stain caused by an as yet unidentified species of fungi. The purple or pink stain also shows the same radial pattern as the blue staining fungi on cross-sectional pieces of wood. As shown in Figure 2, there are some larger sized bore holes and numerous smaller pin holes often associated with dark discoloration seen in ponderosa pine lumber sawed from the standing dead trees. These are created by ambrosia beetles which infest the sapwood after the bark beetle attack and are most numerous in the outer portion of sapwood in the logs. Figure 2 also shows the appearance of sap-stained pieces cut from the logs, and made into dimension lumber. The unstained portions of the pieces are heartwood. The decorative value of beetle-killed wood depends greatly on the methods of processing and marketing. Currently, there seems to be good general acceptance of the color, luster and the way it can be finished.

Figure 1. Selection of logs killed by the bark beetle illustrating the stained patterns on the end sections by blue-staining fungi.

Figure 2. Sawed ponderosa pine dimension lumber from beetle-killed trees.

b. Specific gravity

Specific gravity is an easily determined wood property that is useful as a means of predicting, on the one hand, other wood properties, such as, strength, shrinkage, hardness, shock resistance, etc. and, on the other hand, the value of products, such as, chips for pulp, firewood and briquetts. When wood specific gravity varies, other physical properties are expected to vary also. To obtain limited insight on the specific gravity of beetle-killed wood, 21 full length increment core samples were collected from 21 standing dead ponderosa pine trees in the Poudre Canyon area. The sample was selected from trees that had died within the past 5 years and the size ranged from 10 - 14 inches d.b.h.. All the increment core samples were taken in the zone from about 3 to 4 feet above ground. Specific gravities for the samples are listed in Table 1. For comparative purposes similar information is shown for ponderosa pine trees from the southwestern United States, and the Black Hills of South Dakota (3, 29, 39).

c. Moisture content

Moisture content is important when considering the weight, shrinkage, strength, and other properties of wood and was determined from the same increment core samples used for the specific gravity determinations. In addition a number of full length increment core samples from living trees in the same areas were collected. It can readily be seen from the data in Table 2 that sapwood loses a substantial amount of water after the tree dies. No specific information was available on the rate of moisture loss following the beetle attack for ponderosa pine but according to a study of beetle-killed southern yellow pine (5), the moisture content

Table 1. Comparison of specific gravity of beetle-killed ponderosa pine wood with data from living trees.

	Average sp. gr. (green-basis) unextracted		Remarks
Beetle-killed ponderosa pine from Poudre Canyon	.415		full increment core taken 3 - 4 feet above ground.
	sapwood	heartwood	
	.37	.46	
Living ponderosa pine from Poudre Canyon	sapwood	heartwood	full increment core taken 3 - 4 feet above ground.
	.41	.46	
Southwestern ponderosa pine	.416[1/] - .421[2/]		full increment core samples taken at DBH
Black Hills ponderosa pine[3/]	sapwood	heartwood	
	.40	.48	
	.39	.47	

Source:

1/ Voorhies (39).

2/ Barger et al. (3)

3/ Markstrom et al.(28).

of trees dropped 22 to 53 percent within the first month following attack. The highest moisture content in beetle-killed trees was found at the base and the moisture content decreased with increase in height of the tree. The wood in dead trees becomes drier as moisture content changes to come into equilibrium with the environmental conditions. The amount of drying depends on the length of time the trees have been dead. Furthermore, as the bark breaks up and falls off, checks or splits and internal stresses are generated to a significant degree when the wood dries below the fiber saturation point. Figure 3 shows prominent checks extending deeply into the logs. Wood properties and the product yields are obviously affected by checking of this degree.

Figure 4 illustrates some of the variation with site conditions that can be expected in the moisture content of live trees and differences between sapwood and heartwood of healthy trees.

d. Mechanical strength properties

Strength properties of clear wood specimens for ponderosa pine are available from James (17) Markwardt et al.(30) and the Wood Handbook (37).

The strength properties of beetle-killed ponderosa pine are difficult to relate to the studies which have been done on blue-stain wood in the past (7, 14, 15). The situation is unique in that the wood being studied has been killed and left unprotected in the woods to be subjected to blue stain fungi and other wood-destroying fungi attack for varying periods of time. In addition, weathering degradation of wood, particularly changes in moisture content, also plays an important role in the wood properties.

Table 2. Moisture content of living trees compared to wood of beetle-killed trees.

	Average Moisture Content		
	Sapwood	Heartwood	Remark
Beetle-killed	40	32	Sample taken at 3-4 feet above ground in January in Poudre Canyon area.
Living trees	150	40	
Living trees[1/]	130-150	30	Sample from Black Hills ponderosa pine at breast height.

1/ Data taken from Yerkes' work (42).

Fig. 3. Checks developing in beetle-killed logs.

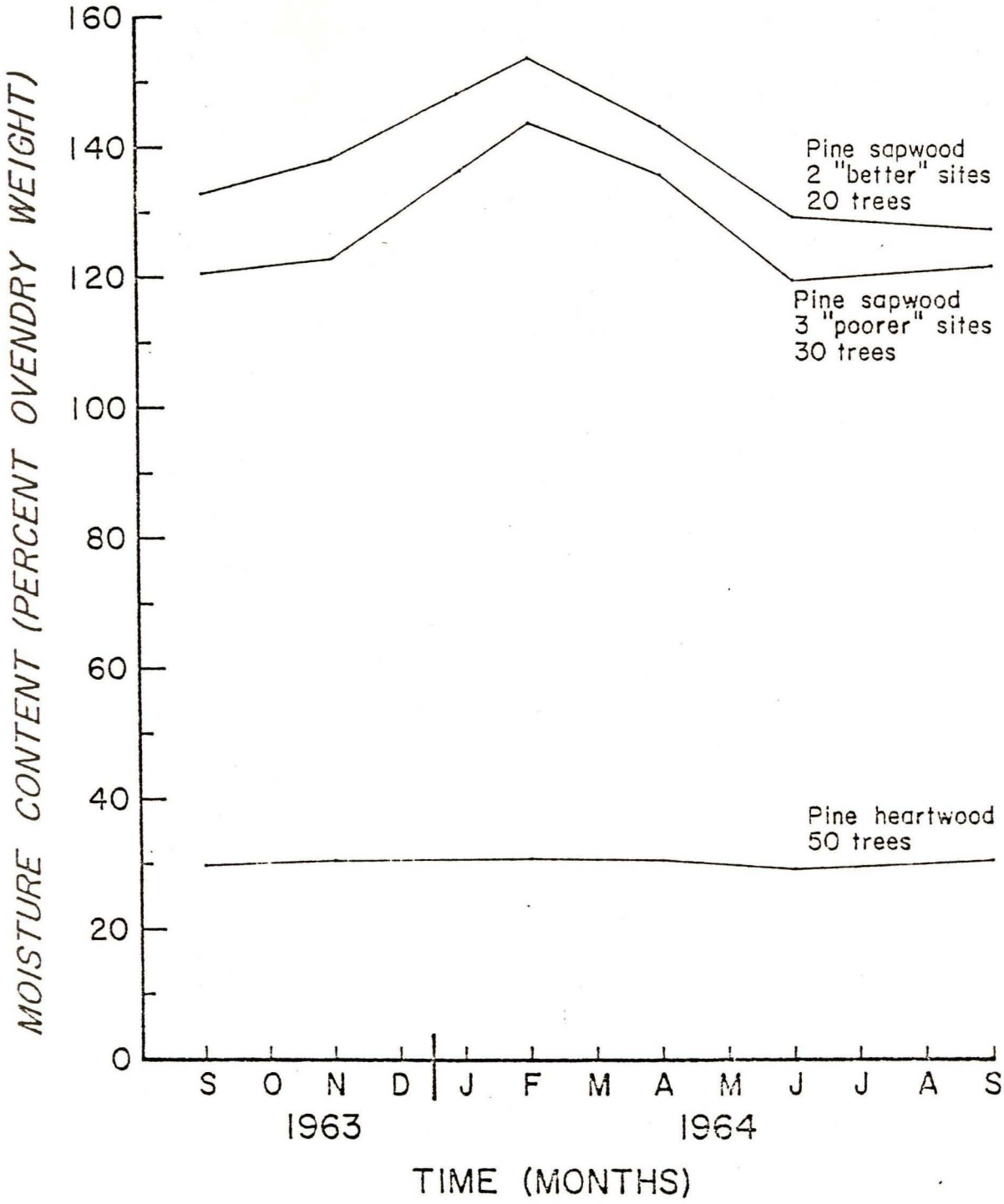


Figure 4. Annual variation of moisture content at breast height for Black Hills ponderosa pine sawtimber trees (Source: Yerkes, 42).

Table 3. Mechanical strength properties of ponderosa pine wood.

	% M. C.	Sp. gr.	Static*							Toughness
			Stress at P.L.	MOR	MOE	Deflection at Max-load	Work to PL	Work to Max	Work total	
			psi	psi	psi 1000	in	in-lb	in-lb	in-lb	in-lb
Radial	Green	.35	2,460	4,170	950	.33	2.1	40	109	144
Tangential	Green	.33	2,000	3,910	840	.36	1.6	40	107	130
Radial	13.2	.36	5,130	8,200	1,220	.22	7.3	42	52	123
Tangential	13.5	.35	4,360	7,630	1,030	.24	6.2	42	44	100

*Rate of deflection - .03 $in/_{min}$

Source: W. L. James, Wood Sci. 1(1):15-22.

Table 4. Mechanical strength properties of ponderosa pine wood.

%	sp.	Stress at P. L. (PSI)	MOR (PSI)	MOE 1000 (PSI)	Work to PL (in-lb/in$_3$)	Work to Max (in-lb/in$_3$)	Work Total (in-lb/in$_3$)	Hardness End	Hardness Side
Green	.38	3,100	5,000	970	.59	5.1	12.4	300	310
at 12%	.40	6,300	9,200	1,260	1.85	6.6	10.8	550	450
Green	.38		5,100	1,000		5.2			320
at 12%	.40		9,400	1,290		7.1			460

Table 4. Continued:

	Compression II stress at PL (PSI)	Compression II max stress (PSI)	Compression I stress at PL (PSI)	Maximum Shear II to grain (PSI)	Maximum Tension I to grain (PSI)	Impact bending height of drop causing complete failure (in)
Green	2070	2,400	360	680	290	20
12%	4060	5,270	740	1,160	400	17
Green		2,450	280	700	310	21
12%		5,320	580	1,130	420	19

Source: Compiled from USDA Tech. Bull. 479 and USDA Agr. Hdbk 72.

Tests were run on small clear specimens of wood dead for one year by Carey (6), who reported that MOR, MOE, compression II and shear perpendicular-to-grain properties all decreased about ten percent and shock resistance (toughness) was reduced by almost 53 percent. The implications of Carey's study and the paucity of data suggest that a more comprehensive study is needed to provide information about wood strength from standing dead trees. The study should compare wood strength for standing trees that have been dead for varying periods of time up to 5 years. Most Front Range ponderosa pine lacks straight-grained wood and the knots are large, which greatly affects many of the strength properties. Possible exceptions are compressive strength and stiffness.

e. Shrinkage and permeability properties

Wood changes dimensions when the moisture content falls below the fiber saturation point. Due to the unique orthotropic property of wood, dimensional changes vary in three mutually perpendicular directions, generally expressed as radial, tangential and longitudinal directions. Differential shrinkage between radial and tangential directions is an indication of wood's tendency to check and warp during drying. In general, the greater the differences in shrinkage the greater will be the severity of drying defects. Since specific information on the shrinkage behavior of blue-stained wood from beetle-killed trees was not available, data from studies based on green ponderosa pine wood are presented. Results of tests conducted by Cockrell et al. (8) on second growth ponderosa pine in California are given in Table 5. The sample trees were full-crowned and the wood was classed as wide-ringed.

Table 5. Shrinkage percentage of California second growth ponderosa pine from green to oven-dry.

	Position of stem		
	stump	16 ft.	32 ft.
Tangential	6.21 - 7.22	5.92 - 6.70	5.45 - 5.91
Radial	2.83 - 3.92	2.61 - 2.94	2.36 - 2.93

Source: Cockrell, R. A. and R. A. Howard. Wood Sci. & Tech 2:292-298.

Table 6. Shrinkage percentage of ponderosa pine from green condition to oven-dry[1/].

Volumetric	Radial	Tangential
9.6	3.9	6.3

Source: Markwardt, L. J. and T. R. C. Wilson. USDA Tech. Bull. 479

[1/] Samples were collected from trees grown in Colorado, Washington, Arizona Montana and California.

According to previous studies (31), blue stain fungi obtain their nourishment primarily from materials stored in the cell cavities of the sapwood; consequently, damage to the cell wall structure does not occur. The wood becomes more porous, however, due to the attack of fungi. The fungi occupy primarily the ray cells and extend the growth and development of the fungal hyphae through the pit structures of cell walls of tracheids

in the sapwood (33). One can expect that the proliferation of the hyphae will affect the moisture content and permeability. However, shrinkage behavior of the wood for a given change in moisture content remains unchanged. Only the percentage of absorption and the rate of penetration of liquids by the wood is increased (25). This phenomenon helps to explain the fast penetration of chemical into blue-stained wood and accounts for the three-fold increase in chemical uptake by the wood in preservative treatment as compared to normal wood. The puzzling fact is the associated wood destructive organisms which may be present in varying degrees with the blue-staining fungi.

f. Solubility changes

Chemical constituents of the wood cell wall undergo degradation when exotoxins are present, as in blue staining and other fungal attack. Measuring the solubility of wood constituents in a one percent sodium hydroxide solution is a way of testing this degradation. In this study, a very limited test of cell wall deterioration was made. The procedures outlined in ASTM D-1109-56 (2) were followed. In the conduct of the test,two bolts of wood from beetle-killed ponderosa pine trees in the Red Feather Lake area were collected as representative of the trees killed in a given year. One specimen was taken from the tree killed in 1973 and the other specimen from a tree which died in 1976. The sapwood of these bolts were ground and the meal between 40 mesh and 60 mesh was used. In addition to the beetle-killed specimens control samples were prepared also from a bolt taken from a normal ponderosa pine tree. Five replications for each of the trees sampled were run and the values are depicted in Table 7.

Table 7. Comparison of the ASTM sodium hydroxide solubility* of wood taken from living and beetle-killed ponderosa pine trees.

Sample No.	Wood from Living trees	Wood from 1976 kill	Wood from 1973 kill
1	11.30	14.91	32.62
2	11.33	14.89	32.59
3	11.38	14.82	32.83
4	11.76	15.01	32.92
5	11.82	15.32	32.98
Average Percentages	11.52	14.99	32.79

*solubility percent based on oven-dry weight of aliquot.

The solubility tests are made on extractive-free wood, i. e., sapwood. The large increase in solubilized substance presumably comes from the main cell wall constituents. Past studies utilizing the one percent sodium hydorxide solubility test dealing with fungal degradation of wood center on the effect of brown-rot fungi. Levi (23) emphasized that brown-rots cause a rapid increase in solubility, due largely to an acidic condition of lignin derivatives, along with a rapid depolymerization of the carbohydrates which takes place, mainly in the amorphous regions of the microfibrils. These results although very limited, may infer an increase in the solubility of beetle-killed material with time after being killed. Nicholas (31) also reported a significant increase in solubility in a one percent sodium hydroxide for decayed wood attacked by brown-rot fungi. Seifert (34) stated that blue stain fungi degraded wood substance and indicated 7 percent

loss of cellulose and a 3-4 percent loss of hemicelluloses. This study, based on the blue stain fungus (Pullulariam pullulans)and pine wood, was conducted in Germany. These results may imply that some fraction of solubilized substances are formed from the attack of blue stain fungus on wood, but mainly, other fungi are responsible for most of the solubility increase.

g. Hydrogen ion concentration (pH).

The hydrogen ion concentration (pH) or in this case, acidity, was tested in cold water (35) by soaking blue-stained wood meal samples prepared from sapwood of sixteen beetle-killed trees. Control samples were prepared from sapwood of normal green wood and by the same method tested. The former gave slightly lower pH values than the latter.

Table 8. Hydrogen-ion concentration (pH) results from green and beetle-killed ponderosa pine wood.

	pH values	Range
Green wood	4.5	4.3 - 4.6
Beetle-killed wood*	4.3	4.0 - 4.4

*samples taken from trees killed within the past five years.

The minor change in pH should not be a barrier for most wood products, including those in which adhesives are involved.

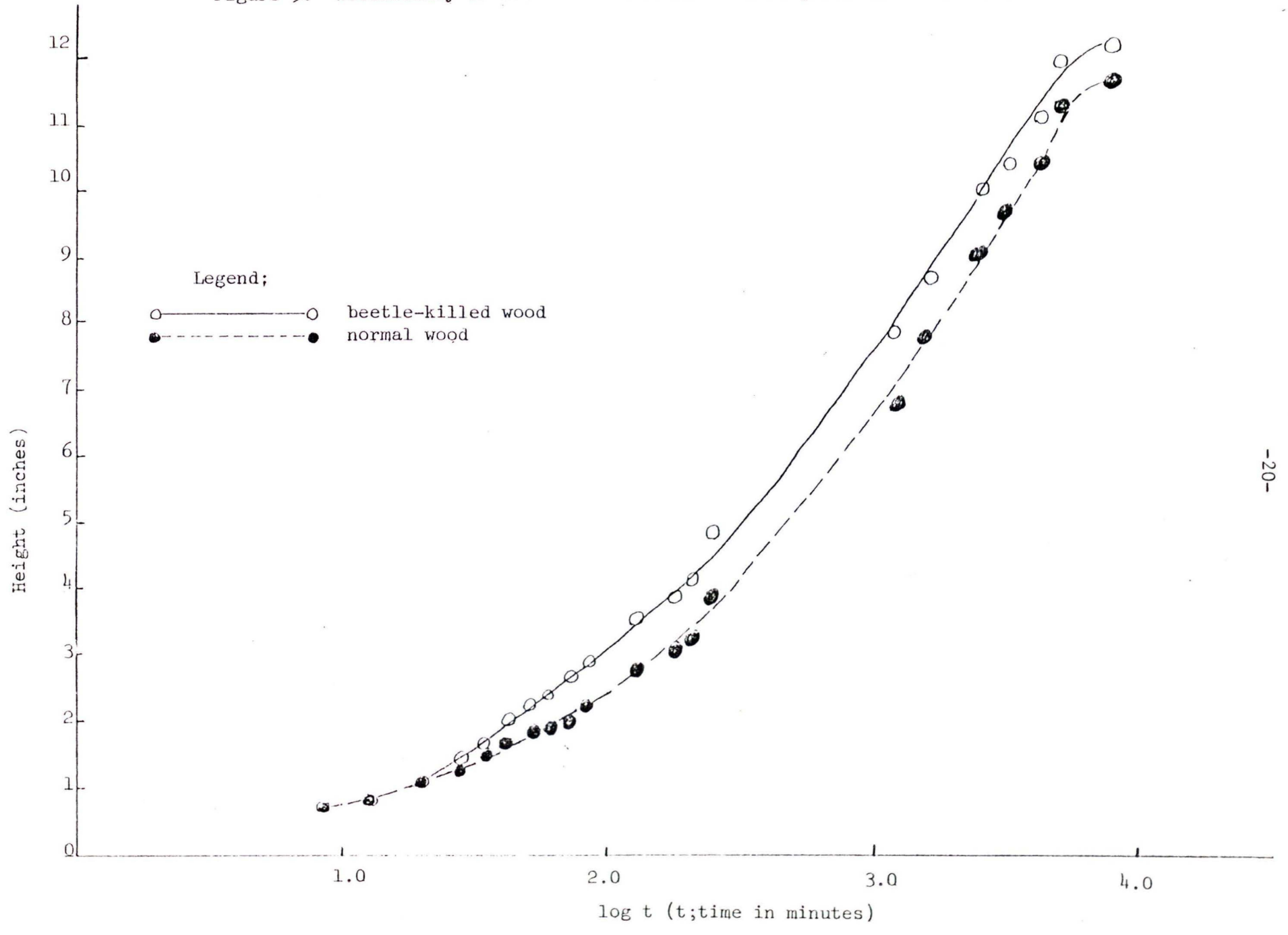
h. Wettability

Wettability is an important property that determines the affinity of wood for liquids, the transfer and the penetration of glue during application and ultimately the quality of glue performance in bonding. A limited effort was made in this study to check the wettability of beetle-killed wood and to compare it with that of normal wood from living trees. Figure 5 illustrates the characteristic beetle-killed wood, which in this case, was taken from trees dead for about 4 years. This comparison suggests somewhat higher degree of wettability for the beetle-killed wood than that from the living trees. The notation "height" in Figure 5 means the height water rises in wood meal when packed uniformly in a three-eighth inch inside diameter vertical capillary tube, when one open end is immersed into a reservoir of distilled water. The moisture contents of wood meal for normal wood and beetle-killed wood used were 6 percent and 5.6 percent, respectively. The heights were measured at different periods of time during the course of the tests until the heights in the columns reached a constant level. From this experiment there is an indication that beetle-killed material may have slightly better wettability characteristics than normal wood, a characteristic helpful in making glued products.

i. Particleboard and screen analysis

Particleboard is a product in which beetle-killed material might potentially be used. In an attempt to assess further the beetle-killed wood properties, the affect of wood bonding characteristics with adhesives

Figure 5. Wettability of beetle-killed wood when compared with normal-living wood.



Upper row - - Beetle-killed wood.
Bottom row - - Normal green wood.

Figure 6. Wood chips made from beetle-killed wood and normal green wood in the laboratory flaker.

Left - - Beetle-killed wood.
Right - - Normal green wood.

Figure 7. Particleboards made in the CSU laboratory from beetle-killed wood and normal wood.

was explored in an experiment where particleboard was manufactured. Five particleboard panels were made from wood chips prepared in a laboratory flaker. A screen analysis was made to compare the differences between the wood from beetle-killed and live trees.

Table 9. Screen analysis comparing on a weight-basis the fragmentation of wood flaked from living and beetle-killed ponderosa pine trees.

Screen sizes	Normal wood	Beetle-killed wood (dead for 4 years)
	Percentage of flakes on screen	
6 mesh	45.5	34.9
6 - 20 mesh	44.5	51.0
20 mesh	10.0	15.0
Average MC percent	6.3	6.0

From Table 9, it is apparent that the quantities of small chip sizes are increased in the beetle-killed wood. This is undoubtedly due to the changes in the physical, mechanical and chemical properties resulting from the deterioration that takes place in the wood following beetle attack.

Figure 6 depicts the chip classification that is presented in Table 9. The row at the top is the screenings of the beetle-killed wood and the light colored chips at the bottom are those made from green wood.

In making the particleboard shown in Figure 7, the furnish particle sizes screened between 6 and 20 mesh were used. Manufacturing parameters are summarized as follows:

(1) panel size; 15 x 15 x 1/2 inches.

(2) mat moisture content, 10 percent.

(3) resin solid was 6 percent urea-formaldehyde.

(4) resin gel time was approximately 2 minutes, based on boiling water gel time method (31).

(5) no wax added.

(6) press platen temperature, 310° F.

(7) press time, 6 1/2 minutes

(8) press closing time, one minute to stop thickness.

(9) panel pressure was 700 psi for first 4 minutes and then backed off to 250 psi for the balance of the press cycle.

Six test panels were made and conditioned in preparation for testing. The appearance of the boards was good. The panels from beetle-killed ponderosa pine have a pleasing blue color but in all other respects are similar to panels from timber cut when green. The boards were evaluated by determining the density, modulus of rupture (MOR), internal bond (IB), thickness swelling (TS) and water absorption (WA) tests. The procedures followed were according to ASTM D-1037-72a, Part 22 (1), except for the water absorption test a sample size of 3 x 3 inches was used, and in the thickness swelling test, only the thickness at the center point of the sample face was measured before and after the water soaking.

The results are tabulated in Table 10. It should be noted that the mean modulus of rupture was above 1600 psi which is the requirement of Commercial Standard, CS236-66 for Type 1-B-1 board, but below 2400 psi, the requirement of type 1-B-2. (38).

Since the wood used in making the particleboard was chipped under extreme conditions to assess the particle fragmentation classification, some substandard particleboard test results were anticipated. Selecting the 6-20 mesh portion for making the panels, where the thickness-to-length ratio of the furnish particles was large, minimal tests values could be expected. Comparative values were the primary purpose. In the internal bond test, the values were very high and a percentage of wood failure was witnessed. In the cases of the thickness swelling and water absorption, the beetle-killed wood values were slightly higher than those of boards made from normal living wood. It is reasonable to expect that the addition of wax into the binder mix should improve these properties. This preliminary testing indicates that it should be practicable to make satisfactory particleboard from beetle-killed ponderosa pine wood.

Table 10. Properties of particleboard made from living and beetle-killed ponderosa pine wood.

	Normal green wood		Beetle-killed wood	
	average	Range	average	Range
Density (#/ft^3)	48	46.5 - 50.7	46	43.1 - 48.1
MOR (Psi)	2,338	2,086 - 2,605	2,145	1,776 - 2,565
IB (Psi)	192	157 - 215	178	165 - 189
Thickness swelling (TS) (% of original thickness)	40.7	40.1 - 42.1	44.3	42.5 - 47.3
Water absorption (WA) (% of final weight)	47.3	46.3 - 48.9	51.5	50.1 - 52.4
M.C. of samples (% of oven-dried wt).	3.94	3.89 - 4.05	4.01	3.97 - 4.07

III. SUITABILITY OF BEETLE-KILLED WOOD FOR VARIOUS WOOD PRODUCTS

An efficient and effective utilization program for Front Range beetle-killed ponderosa pine requires a diversified product mix because there is a wide variety of tree sizes and volumes per acre to be removed from the forest resource base. New products not now being produced in the area must be considered if the volume of live and dead is to be used. The best information presently available has been considered in evaluating the suitability of the available material for various products.

A. Products presently available in Colorado Front Range area.

The major wood products currently being manufactured by Colorado Front Range wood-using industry from ponderosa pine were first investigated. The information collected provides the main basis for predicting suitable wood products for the beetle-killed ponderosa pine wood resource from Front Range forests. Important product requirements and characteristics are noted and the suitability of the available dead timber for these major wood products is discussed. The relative importance of these major wood products in the area is indicated by the mill capacity for each individual wood product as listed in Table 11.

a. Boards, dimension lumber and timbers

Sawtimber comes from trees 9 inches D.B.H. and larger and to a top diameter of five inches. As a result of the increasing pressure to utilize residuals and younger and smaller trees from second growth stands, the proportion of small logs yielding low grade boards, dimension lumber and timbers is increasing. Knots are the defect of major concern. Their presence in boards, dimension lumber and timbers causes distortion and discontinuity of grain surrounding them, which together with the higher density of knots result in

Table 11. Summary of estimated processing capacities by product, for the Front Range.

Wood Product	Processing Capacity (MCF)
Board, Dimension Lumber & Timber	3021.2
Paneling	230.9
Pallets	523.9
Fencing	230.7
Studs	70.8
Poles, Fence Post	1592.5
Houselogs	642.7
Firewood	1836.0
Chips, sawdusts & shavings	4446.5
Miscellaneous	633.4
Total	13228.6

Source: Love, R. et al. Unpublished paper. Rky Mtn, For.& Range Exp. Sta. USDA For. Serv. (24).

irregular shrinkage behavior and therefore, increases the possibility of crook, bow, cup or twist during seasoning. When lumber dries, knots shrink more than the surrounding wood and this causes checks to develop, loosened knots or in some case, the knots drop out. When areas of irregular grain and drastic variation in density are present, wood strength is reduced and wood machining becomes more difficult. Such defects result in torn grain, and cross-breakage in manufacturing. Other properties affecting quality of these products are cross grain, checks, splits, shakes, pitch and bark pockets, stain, decay, etc.. Timber products have a tendency to check more severely

than dimension lumber and boards but usually warp less. The size of knots permitted in various boards, dimension lumber, and timbers is governed by the proportion of their diameter to the width of the piece containing them as well as by their location in the finished product. Figure 8 illustrates the various sizes and grades of boards, dimension lumber and timbers typically produced.

A lumber grade recovery study has been conducted jointly by the Pacific Northwest Forest and Range Experiment Station, Rocky Mountain Forest and Range Experiment Station, Colorado State Forest Service, and the Front Range forest products industry to determine the comparative lumber recovery from live and dead trees. This will be most helpful in evaluating the suitability of the dead timber for boards and dimension lumber. While the final results are not yet available, observations and discussions during the course of the experiment are thought to be worth mentioning. It is quite possible that lumber yield from some standing dead timber may approach that for live trees. However, in general a higher percentage of utility or low grade products will likely be obtained, from the logs of dead trees. More narrow boards from the logs of dead trees are also expected. The general concept that the higher grade lumber is cut from the clear outer sapwood layer of live trees may not apply to beetle-killed trees due to the fact that stain, decay, and insect attack most frequently occurs in that area. The information derived from this comprehensive study should help provide the kind of information required to utilize best the volume of beetle-killed material available.

b. Paneling

Paneling is a high value product that can yield a high return to processors. Boards of grade No. 2 common or better cut from logs 10-11 inches and larger in diameters are frequently selected for making paneling. Boards 6-8 inches wide are commonly used. Blue staining fungi in the sapwood of standing dead trees present no special technological problems in the manufacture of paneling, and the natural discoloration in the wood, makes it attractive to many users for decorative interior paneling. In the Front Range region some blue-stained paneling from beetle-killed ponderosa pine wood is now being manufactured and marketed successfully (Figure 9.).

It is important to maintain high manufacturing standards in producing blue-stain paneling. Paneling for interior use should be delivered at the in-service moisture content to assure best performance. There is a question as to whether kiln-drying is necessary. It has been well-established that fungi activity is arrested when the moisture levels fall below 20 percent, but insects such as roundheaded borers, termites and carpenter ants may be present in beetle-killed trees whose eggs and larvae need to be killed by subjecting the wood to temperatures over 180°F. The likelihood of insects being a major problem is not great but caution is appropriate in producing and marketing a product of this class.

c. Pallets

The lumber generally used for manufacturing pallet parts in the Front Range of Colorado comes from the lower grades, usually No. 2 or 3 Common grades of such softwood species as ponderosa pine, lodgepole pine and spruce. Dry lumber is preferred since pallets made from green or

Figure 8. Various sawn products from beetle-killed logs--boards, dimension lumbers and timbers.

Figure 9. Blue-stained paneling.

partially dried lumber may fail prematurely if the boards warp, check or split at the fasteners. Preservative or water repellent treatments will extend the service-life of pallets especially if they are used under the exposure conditions where excessive moisture and insect attack are possible. If chemicals are to be applied, caution must be exercised to assure that the product complies with acceptable environmental and anti-pollution practices, particularly for those pallets used with, or around, foodstuffs or other materials where toxic contamination is a possibility. One manufacturer has experienced rejection of blue-stained wood in pallets by a customer who uses pallets in contact with foodstuff. There is no evidence, however, that blue-stain is harmful in this respect. As used in pallets, wood is often loaded as a beam, and therefore, its bending strength is perhaps the most essential property. Other properties - compression strength, shock resistance and nail-holding power are also major considerations. Naturally occurring defects; such as, knots, checks, splits, shakes, diagonal or spiral grain, pitch pockets, and decay greatly affect strength of wood and consequently affect pallet performance. Blue-stain pieces, especially from standing dead timber, should be examined carefully and determined to be sound wood before they are selected for pallet construction.

d. Fencing

Slabs from sawlogs and smaller stud logs are the raw material generally used for manufacturing fence boards. Production of fencing at a sawmill therefore provides an outlet for utilizing what is often mill residue. There is a huge market for fencing in the Front Range because of the current building boom. Producers of wood fencing are probably not capitalizing fully

on the market demand because of their lack of capacity to produce and market this product. Appearance is important for fencing as well as some resistance to decay, insect attack and weathering. Fencing consists primarily of vertical boards or battens, rails and posts. Fence boards for specific designs may require a minimum amount of wane, bark, checks, shakes, fire and lightning scars, but these are not deterrents to a good service-life. However, knots can be very important. If they are large, they will reduce the service-life. Even though they may enhance the appearance, they give lower wood strength properties. Of all the important strength properties, nail-holding power and bending strength are of major importance for installation and long performance of fencing. There are few difficulties in the manufacture of fencing products from beetle-killed ponderosa pine wood. Protection against fungi and insects can be improved by simple preservative treatments. Figure 10, illustrates use of beetle-killed wood for functional decorative fencing.

e. Studs

All sizes of logs above a five-inch minimum diameter are suitable for producing studs. The cost of harvesting and processing and timber quality determine whether studs can be produced economically. The principal use of studs is in the construction industry. The characteristics of knots grain deviation, decay, checks, split, heavy stain, bark and pitch pockets, and wane are important criteria in stud grading; however, straightness is perhaps the most vital. Blue-stained wood is allowed in stud manufacture and grading but decay is restricted. The suitability of beetle-killed wood for studs depends on the degree of deterioration. Figure 11 shows straight 2 x 4's made from dead ponderosa pine. Generally, the sound wood of beetle-killed ponderosa pine should perform satisfactorily for studding as long as the pieces are straight after drying to an in-service moisture content.

Figure 10. Fence posts, fence boards and rails from beetle-killed logs.

Figure 11. Two-by-four studding of beetle-killed wood.

f. Round timbers

Wood is used in many different ways. As round pieces ponderosa pine is widely used for fence posts, barn poles, corral poles, mine props, utility poles and piling. Utility poles and piling are not major uses for Front Range ponderosa pine because of the tree form. Utility poles need to be straight and cylindrical with a gradual taper and free from excessive checks and defects. Piling must be relatively straight. Both require preservative treatment.

The round wood product most commonly produced from ponderosa pine is fence posts. They are usually 6 to 8 feet long and measure 2 to 8 inches in diameter at the small end. Most fence posts are round in cross-section but some are squared. The heartwood of this species is non-durable when exposed to the soil, however, the wood treats easily with preservatives. Posts treated with an effective preservative should have a service-life of 35-40 years. The natural defects commonly found in the wood of small diameter trees are not usually a detriment to fence posts.

Corral poles are produced in this region and widely used as rails in fencing. They are 2-7 inches in minimum diameter and vary from 8 to 20 feet in length. Sometimes they are used with the bark on but most often they are peeled. Most corral poles are used untreated and have a good service-life when not subject to continuous moisture. Preservative treatment, staining, or painting can help protect the wood from destructive organisms.

Barn poles are another product frequently made of ponderosa pine. Acceptable pieces are those with little or no sweep, crook and taper. Excessive knot clusters are undesirable. They usually have a 4-to 8-inches minimum diameter and vary in length from 8 to 24 feet. In most cases the wood is preservatively treated for this use.

Mine props are a form of roundwood used widely in the mines of Colorado. Most of the props are used in coal mines and used untreated. They are 4 to 8 inches in minimum diameter and 6 to 8 feet long. Price is usually the determining factor as to what material will be used.

Of the round timber products discussed beetle-killed material is probably most suitable for fence posts, barn poles, corral poles, and mine props. It would be least suited for utility poles and piling.

The presence of blue-stain should facilitate preservative treatment, but this may be regarded as a problem by the industry since stained wood tends to absorb preservative at rate three times faster than unstained wood and tends to retain more of the preservative than is required. For the most part the normal characteristics of ponderosa pine do not limit its use for roundwood products except as previously noted.

g. Houselogs

A product of ponderosa pine which has not been publicized greatly but is widely used in structures is the houselog. The log structure offered a quick and efficient method of construction to those that settled the West. As building grew and raw material diminished in the immediate vicinity of settlements it became more efficient to erect structures from sawn wood. Today many people want the aesthetics and romanticism of yesteryears but at the same time the comfort and conveniences of modern technology.

A revival of the houselog in many forms is now being seen throughout Colorado with many attractive structures being built for use as cottages, motels, churches, restaurants and family residences. Ponderosa pine is not the most widely used houselog species but satisfies a market for logs 7 inches in diameter and larger at the smaller end and 20 to 24 feet

There are no specific restrictions which preclude beetle-killed logs from being used. In fact, the industry primarily uses sound dead trees because the moisture content is closer to the in-service conditions and fewer fabricating problems are encountered. Houselogs need to be dry when they are cut and fitted. The presence of abnormal wood and irregular grain may present problems in cutting logs. There are no major deterrents in using beetle-killed trees for houselogs. The important feature to be considered is that houselogs require relatively sound logs as a raw material.

h. Firewood

Fuelwood for domestic heating, cooking and industrial use has been virtually replaced in Colorado by gas, coal, oil and electricity. There has been an increased interest, however, in wood as an alternate and supplemental heat source for homes since the oil and gas crisis of 1974. It appears that solar heating may receive much more attention as an alternate heating source, but the increased use of fireplaces is inevitable and a high percentage of new living units have fireplaces. It is not uncommon for new single family units to have more than one fireplace.

It is estimated that tons of ponderosa pine firewood is currently being utilized in homes located in and contiguous to the Front Range area. About one quarter of the volume used is by the individuals who cut their own firewood. Wood as a fuel is limited mainly to fireplaces, however, some wood burning stoves are in use.

Ponderosa pine as a fuelwood has the following characteristics: it (1) gives a heat value of about 9,000 B.T.U.;s per pound of dry wood; (2) ignites easily; (3) rapidly produces a hot flame; (4) burns clean with only about one percent ash content by weight; (5) is bulky with high transportation costs (6) must be dry to obtain full heat value; (7) is difficult to obtain in uniform quality and (8) has a fragrant quality when burning which encourages its use.

The heat value of ponderosa pine is about 25 percent less than coal and approximately 50 percent less than oil on the basis of weight.

Dead ponderosa pine is well-suited for firewood due to its low moisture content, which makes it ready for market with less drying time and its high resin content, which makes it ignite and burn more readily than some other less resinous woods. Firewood is commonly measured and sold in standard cords, a stacked unit equivalent to 4 x 4 x 8 feet, or 50-90 cubic feet of solid wood depending on the size of the pieces and how-tightly stacked. Occasionally firewood may be priced by weight.

B. Potential new products

a. Composite panel products

There is an excellent technical potential to utilize the available raw material for making composite panel products from ponderosa pine. Ponderosa pine wood and fiber is particularly well-suited for products of these kinds. Particleboard utilizing ponderosa pine is manufactured and widely marketed in the western region of United States.

Studies by Barger et al. (4) and Markstrom et al. (28) that evaluated production of particleboard with UF and PF resins from ponderosa pine roundwood, as well as sawmill and forest residues, have indicated very favorable results. Recently, laboratory work on evaluation of composition board from white pine and lodgepole pine (27) revealed that furnish from standing dead trees of these species showed little difference from that of live trees. A problem with the internal bond characteristics of structural flakeboard made from this material was attributed to poor flake surface quality. The occurrence of the poor surface faculty is the result of flaking dry wood which is normally associated with dead timber. Linear expansion was reported to be relatively higher on boards made from both live and dead lodgepole pine. Lehmann and Geimer (21) working with Douglas-fir forest residues for structural particleboard stated that panels containing sound (sic) dead wood with incipient decay suffered little or no loss in either strength or dimensional stability properties when compared to the control panels made from live wood. It was found that only when badly decayed wood was added to the raw material was the quality of the board seriously affected.

In this study, no exhaustive effort went into the technical feasibility of manufacturing particleboard from standing dead ponderosa pine wood. It is apparent that suitable furnish can be made from beetle-killed ponderosa pine; however, a wide variety of trees of different sites in the Front Range has not been collected for making the various composite boards. In addition, how well this furnish can be mixed with that of other available species needs to be determined. Indications are that a satisfactory board can be produced from the beetle-killed component of the Front Range resources, and in our

estimation ample mill and forest residues exist in the Front Range to supply a mill of economic size. A critical factor in composition board production is the ability of the producer to obtain raw material delivered to a mill site at a cost low enough for the finished product to compete at the market place. The feasibility of producing and marketing medium density fiber board and/or particleboard should be tentatively considered an option in utilizing wood resources in the Front Range of Colorado.

b. Plywood

The available live timber resource could produce a quality veneer and would be worthy to consider as plywood. In addition to important physical and mechanical properties of wood,tree sizes and form along with the knot sizes and other defects determine the veneer yield and grade. Yerkes and Woodfin (41) studied veneer recovery from 144 selected Black Hills ponderosa pine trees and found veneer yield was 45 percent of the cubic-foot volume of the sample trees. The majority of the veneer grade recovered is C-D grades and knot size was found to be the major factor that determined grade. These results may or may not apply to ponderosa pine grown in the Colorado Front Range region. It is doubtful since the trees in Colorado may vary in size and quality. It is not possible to relate the Black Hills observations to beetle-killed wood because the expected yield would be notably lower due to the comparatively higher percentage of defective material. A lower and more variable moisture content of beetle-killed trees would result in many more veneer cutting problems. Lutz (26) pointed out, however, the problem can be reduced

by putting water back into wood before cutting. In the CSU laboratory experiment on particleboard, the more permeable beetle-killed wood did not cause any appreciably detrimental effect in gluing particleboard. It is therefore reasonable to assume no gluing problems should develop with veneer. Since there were no drastic differences in pH values, between live and dead material, veneer from dead trees could be expected to show good glue bonding characteristics. Blue stain, the degree of wood deterioration and the concomitant weakening in mechanical strength properties of wood limit the suitability of the veneer and plywood made from beetle-killed wood for many uses.

It is cautiously opportunistic to predict that satisfactory plywood could be manufactured from a combination of beetle-killed and live ponderosa pine, but the technology needs further investigation. The availability of sufficient resources seems the most questionable feature of construction and industrial plywood feasibility.

c. Pulp and paper

The technical feasibility of using beetle-killed ponderosa pine wood for pulp and paper products depends on the effects of certain wood characteristics including mositure content, blue-stain fungi and deterioration of wood by decay, on the quality and yield of pulp and on the consumption of chemicals. Information on the combined effects of these factors is scarce. Levi and Dietrich (22) claimed that the chemical requirement increases with the percentage of blue-stained wood involved and the degree of pulp whiteness desired. The pulp yield and strength from blue stain fungi infested wood is not known. Needless to say, decay in wood would seriously reduce both yield and quality of the pulp.

As reported earlier in this paper, solubility tests with one percent sodium hydroxide revealed a weight loss of about 33 percent from one dead tree killed by beetles 4 years earlier. This compares to a weight loss of about 11 percent from the normal wood samples. This evidence is unfavorable when considering pulping. Further study should be undertaken to verify these results based on this preliminary study. It is obvious that the degree of decay will affect the acceptability of beetle-killed ponderosa pine wood for pulping; however, blue stain alone should not prevent use of this raw material for pulp and paper. Bleaching a 95 percent blue-stained sulfate pulp required only 2.5 to 5 percent more standard bleaching agent than unstained pulp (22). This is a slightly higher chemical usage but does not negate the fact that pulp of good quality and strength can be produced from blue-stained wood. Experience with wood tells us that dry wood is harder to treat with chemicals due to the lesser availability of accessible interstitial space in the cell wall and the large amount of air entrapped in the wood. However, evidence also shows that beetle-killed sapwood while quite dry may have increased permeability due to blue stain. Further pulping studies may be needed to provide answers to specific pulping problems.

At the present time a great deal of mill residue is being chipped and shipped to pulp mills in the Lake States, but increasing shipping costs and limited markets for the chips suggest that a pulp mill nearer the raw material may be a consideration. The high capital cost of a pulp mill, large water requirements, and pollution hazards all militate against conventional installations. The Front Range situation probably would require a pulping method which has low water requirements, minimal pollution hazards, and a small capital investment.

d. Laminated wood

Colorado's wood industry is being challenged to tap market opportunities for local wood species not fully used. The use of ponderosa pine and specifically beetle-killed wood for laminated wood products is one of the possibilities. The prime advantage of laminated wood lies in the ability to upgrade product performance and values.

Through lamination, wood can be modified to place laminae of the greatest strength in sections of a member where highest stresses will occur. The biggest gains come from combining strength properties with the possibility of making large-sized laminated wood products from small diameter trees. A group of products based on these advantages is still developing. Beetle-killed wood should be suitable for many laminated wood products. Careful selection of pieces would control the quality and eliminate the danger of inadequate material going into products. Recent studies at Colorado State University with lodgepole pine (King (18) and Tichy (36)) suggest that laminated dimension lumber is a potential product which should be actively considered for beetle-killed ponderosa pine. Because a shortage of dimension lumber exists and practically all dimension lumber consumed in Colorado comes from outside the region, distinct advantages are apparent for a suitable and competitive, local product to be produced. Through the use of a laminating process, dimension lumber of 2" x 10" x 16'; 2" x 12" x 16' and 3" x 8" x 16' nominal joist sizes containing 5 or 10 laminae have distinct possibilities.

Results using lodgepole pine showed upgrading of strength properties from low-grade small logs by laminating. Manufacturing costs developed showed an added manufacture cost of over the cost of making solid sawn wood members (18). The favorable results reported provided encouragement that similar research should be actively pursued for beetle-killed ponderosa pine.

IV. POTENTIAL MARKETS

In analyzing the suitability of beetle-killed wood for products that can be produced in the Colorado Front Range area, it is essential to investigate marketing potential. An important aspect of marketing is the cost of production and transportation a product can bear.

Table 12 gives a picture of the average cost of delivering raw materials in the area. The cost of obtaining raw materials in the area north of Denver seem to be somewhat lower than in the southern area.

Table 12. Cost of delivered raw materials.

	Sawtimber (Per MBF)	Fuelwood (Per CCF)	Poles (Per Cord)
Stumpage	$2 - 25.27	$ 1.89	.50
Harvesting	$38.84 - 51.37	$22.19	19.12-19.28
Transportation	$7.37 - 25.86	$ 9.97	11.48-12.33
Total Delivered Cost (including profit and risk)	$64.02 - 104.22	$46.38	37.58-46.38

Source: Love, R. et al. Unpublished paper. Rky. Mtn. For & Range Exp. Sta USDA For Ser. (24).

Lumber is the predominant product in the Colorado wood industry. Larson (19) pointed out that production of lumber in Colorado in 1970 amounted to 244.8 MMBF, of which 150 MMBF are shipped out of the state. In the same year, however, 677 MMBF of lumber was imported. There were 22.3 MMBF of timbers imported as compared to 16.1 MMBF produced in Colorado in 1970. These figures indicate that a large local market is potentially available for local lumber products. However, improved manufacturing techniques as well as new products may be needed for local products to replace some of the imports.

Table 13 shows average product values for wood products in Colorado Front Range area.

Table 13. Product values of Colorado Front Range produced wood products.

Product	Product value Dollars/MCF (F.O.B. Mill	Product	Product value Dollars/MCF (F.O.B. Mill)
Pallets	3,000	Fence post	3,372-4,069
Timber	1,920-3,408	Rough boards	1,740-1,800
Fencing	3,240	Planed boards	3,474-3,840
Dimension lumber	2,400-2,640	Studs	3,291
Barn pole	3,360-3,564	Paneling	5,485
Houselog	1,720-2,437	Firewood	529-768
Corral pole	2,880-3,038	Chips	28-125

Source: Love, R. et al. Unpublished paper. Rky, Mtn, for. & Range Exp. Sta. USDA For. Serv. (24).

Presently, mill capacity in the area amounts to approximately 230.9MCF/per yr. In order to utilize the available wood and fiber resulting from the beetle infestation, the mill production will have to reach full capacity and

additional producing units will be necessary.

According to a recent study on the production of wooden poles and posts in Colorado by Gaither (16), a total of 767,987 barn poles, fence posts and corral poles were produced in 1975. The Front Range of Colorado accounts for more than 80 percent (614,389) of all poles and posts produced annually in Colorado. This quantity is far less than the 2.6 million wooden posts proposed by Crews (9) in 1968 as the annual demand in Colorado.

Fuelwood consumption in Colorado's Front Range was given as approximately 81,617 cords or 6.5 MMCF for 1976 by Region 2, Forest Service, USDA. In the same year, it was estimated 27,097 cords or 2.2 MMCF of ponderosa pine fuelwood were used.

Apparently the market opportunity exists and the potential growth is greater than the existing product capacity of 1.8 MMCF given for the area in Table 11.

Denver and Fort Collins manufacturers produce the majority of houselogs and fencing in the Front Range of Colorado. These mills are operating at about 40 percent of their capacities. The primary houselog market for these firms is within Colorado.

The wooden pallet industry has been described as growing at a phenomenal rate. In 1974 estimated production exceeded 205 million units in the United States (11). The lumber requirement for pallet manufacture was 15 percent of the entire lumber production in the United States in 1974. The outlook for an expanding pallet market remains very bright.

Eagan (10) investigated the market potential for particleboard produced in the Rocky Mountains. Based on markets he suggested that the central Rocky Mountains region might be a feasible location for a plant. Larson (19) and

others have also suggested the possibility of a central Rocky Mountain particleboard plant, based on the abundant small roundwood volumes, the volume of mill residues available and the transportation advantage to north-central United States markets over particleboard mills located on the West Coast. Markets and manufacturing limitations do not appear to be the criteria which impedes development of composite board but rather raw material cost and availability are most often mentioned.

Although there is an ample potential supply of pulpwood and seemingly favorable market opportunities for newsprint and containerboard (20), the establishment of a pulp mill has not yet occurred in Colorado. There appears to be too many elements of risk to justify profitably and long term continuous operations. The elements questioned most frequently are associated with the water requirements and the attendant environmental factors.

Ponderosa pine is a suitable wood species for plywood manufacture. However, this has not been demonstrated specifically for Front Range ponderosa pine. Plywood markets for potential Rocky Mountain production were studied by Wangaard et al. (40). The results suggested an increase in the markets for residential, industrial, general construction and in the agricultural markets in the 1970's and indications are that rapid growth is being experienced. Although the markets show a rapid expansion in the Rocky Mountain region for plywood, there is some concern as to the potential of fiberboard or particleboard.

Harvesting, transportation and processing costs of raw material has been presented in this section. The cost represent those for both live and beetle-killed trees. Obviously, the costs vary widely and depend upon the logging conditions, and mill characteristics. The

principal cost variables between live and dead trees appear to have off-setting features. Detailed studies appear necessary to develop meaningful information for the various cost centers.

The types and sizes of markets for beetle-killed ponderosa pine are optimistic indicators. The prices of beetle-killed products do not appear to be suppressed and in some cases they bring superior prices in the market place. The volume of beetle-killed products reaching the market place is not great and markets show no signs of saturation, however, the marketing phase of the project will be able to elaborate further on markets and the marketing of beetle-killed products.

V. SUMMARY AND CONCLUSION

The wood of ponderosa pine exhibits color of light reddish to orange brown in heartwood and white to pale-yellow in sapwood. The wood is classified as medium-course in texture and light in weight with an average specific gravity of 0.41, ranging from 0.39 for sapwood to 0.47 for heartwood. Its mechanical strength properties are moderate. Ponderosa pine has good machinability and excellent gluing characteristics. The wood is considered suitable for a wide variety of wood products. To date, in the Colorado Front Range, an estimated loss of ponderosa pine of 5,584 MCF annually by mountain pine beetle infestation has been reported. The mountain pine beetle infestation results in the introduction of blue staining fungi into the wood and the death of the tree. Consequently, the sapwood is heavily blue-stained. Frequently noted in sapwood associated with blue stain is some pink or purple stain caused by an as yet unidentified species of fungi.

In order to determine the conditions of the wood of beetle-killed trees, selected physical, mechanical and chemical properties of the wood of trees which has been killed for varying time periods up to 5 years were investigated. In addition to the presence of blue stain in sapwood and beetle galleries in the inner bark of the wood, numerous smaller pin holes and some larger bore holes caused by various insect attacks are present in sapwood, resulting in substantial degradation of the wood. A solubility test of wood samples taken from one beetle-killed tree dead for four years revealed a 33.0 percent solubility, compared to 11.5 percent for normal wood samples. These results suggest a rapid invasion of the wood by decaying fungi after the tree has been beetle-killed. The density of beetle-killed wood samples did not show significant changes from normal density. The results of moisture content determinations indicated that sapwood loses water quickly, while the heartwood moisture content drops slowly after the tree dies. One effect of this is checks in the wood.

Several mechnaical strength properties tested suggested a decrease of about 10 percent for trees dead for one year. However, toughness was reduced by about 53 percent. The test of hydrogen ion concentration (pH) on beetle-killed wood gave slightly more acidic values in the range of 4.0 to 4.4 as compared to the values in the range of 4.3 to 4.6 for normal wood. The beetle-killed wood is more permeable and more easily penetrated by preservatives. It is also more wettable and therefore more easily glued, as observed from a wettability test.

It is believed that the shrinkage of beetle-killed wood remains the same as that of normal wood, providing decay is not present in a significant amount. Evaluation of particleboard indicated that since physical, mechanical and chemical properties are altered, beetle-killed wood gave a higher proportion of small chips than normal wood, when chipped in a laboratory flaker. Boards made from two types of chips showed high internal bond, indicating that beetle-killed wood can be glued satisfactorily. Similar particleboard properties were found for both types of boards. Only slightly higher water absorption and thickness swell values were detected for particleboard from beetle-killed timber. These were not considered serious, since the addition of wax to the furnish is normal for particleboard manufacture and would help overcome this deficiency.

In general, characteristics of beetle-killed wood vary with length of time the trees are dead, and the longer dead trees are left in the woods, the higher the risk of excessive deterioration. About five years appears to be the outside limit for the length of time dead trees remain in a utilizable condition.

Colorado Front Range wood-using industries produce a wide variety of wood products. They include boards, dimension lumber, timbers, paneling pallets, studs, poles, fence posts, houselogs and firewood. The characteristics of these products were assessed according to their product requirements.

Timber coming from a beetle control program could provide the industry with wood of a quality suitable for current manufacturing; however, limitations do exist. To answer a number of technical questions, more comprehensive studies are needed to classify the raw material. Also, more intensive studies should be done to evaluate the details of wood and fiber properties as they relate to processing and products. New products which

are not indigenous to the area should be introduced; namely, wood-based fiber and particleboards and specific kinds of laminated wood products. More product outlets are required. It is encouraging, however, that the current national and regional economy seems to indicate markets will exist for a greater volume of wood products that can be produced from beetle-killed trees of the Front Range area of Colorado. Future forest management should emphasize utilization of this wood resource so that the area's forests can be placed in a healthier growing condition to achieve better long term control of the mountain pine beetle.

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